FACILITY LAYOUT AT MCNEIL WAREHOUSE GOODWILL INDUSTRIES

Clara Novoa, Nhi Mai,
Texas State University, Ingram School of Engineering, Industrial Engineering Program,
San Marcos, TX 78666, USA
cn17@txstate.edu, nm1178@txstate.edu, (512) 245-4343

ABSTRACT

This paper presents two new facility layouts for a warehouse which save 89,946-101,449 traveled feet/day. The need for a new layout came after Goodwill Industries of Central Texas consolidated operations performed at McNeil and Springdale warehouses into McNeil. Several scenarios were studied and the solutions from using the CRAFT heuristic were compared to the original layout.

Keywords: Facility layout problem, quadratic programming, CRAFT heuristic, lean manufacturing

1. INTRODUCTION

Management at Goodwill Industries of Central Texas decided to consolidate some warehouse operations performed at both McNeil and Springdale warehouses into the McNeil facility. This created an immediate need for a new layout for the McNeil warehouse. Since management was willing to rearrange all current McNeil warehouse operations but some were more expensive to relocate, different alternative layouts were generated using the CRAFT algorithm found in the WinQSB program. As mentioned in (Drira et al., 2007; Tompkins et al., 2010) when studying facility layout alternatives good placement of facilities contributes to the overall efficiency of operations and can reduce up to 50% the total operating expenses. It is also crucial that the layouts depend on realistic requirements and be robust and flexible in responding to uncertainties (Kulturel-Konak, 2007). In this research, after various layouts were produced, a single one was chosen to fit the desired set of operations and departments at the McNeil warehouse.

This paper is divided into six sections. Section two mentions some previous work regarding the facility layout problem and methods for its solution. Section three explains the warehousing operations required at the McNeil warehouse. It also mentions the way information about interdepartmental flows was collected and its relevance. Section four describes the facilities layout problem at McNeil warehouse and the methodology used to solve it. Section five presents the numerical results and section six provides conclusions and directions for further research.

2. LITERATURE REVIEW

Because this study is specifically for the McNeil warehouse, previous work does not research exactly on the same problem. Nonetheless, there are many publications which discuss several generic mathematical programming formulations for solving facility layout problems (FLP's)

(Chang, 2003; Drira et al., 2007; Kulturel-Konak, 2007; Meller & Kai-Yin, 1996; Rardin, 1998; Singh & Sharma, 2006; Tompkins et al., 2010). (Drira et al., 2007) mention that the formulations may rely on different approaches, such as graph theory, quadratic assignment problems (QAP) for discrete formulations, Mixed Integer Programs (MIP) for continuous formulations, and fuzzy theory for cases when it is argued that the available data is maybe not perfectly known.

As stated in (Kulturel-Konak, 2007), production uncertainty is one of the most challenging aspects in manufacturing environments. Therefore it requires the most recent advancements for designing robust and flexible facilities. (Kulturel-Konak, 2007) presents the dynamic facility layout problem (DFLP) that considers several production periods as a modeling approach to design robust and flexible facilities. Exact, heuristics, meta-heuristics, and hybrid methods for solving the DFLP are discussed. . (Kulturel-Konak, 2007) mentions that the CRAFT heuristic adapted to solve the multi-period situation in the DFLP has relative success since it avoids the complexity and intense computational demands of the Dynamic Programming and Quadratic Assignment problems, performs slightly worse than optimal procedures, and is an effective heuristic method.

In (Drira et al., 2007) a discussion of solution approaches to the FLP is included. The authors mention that exact methods are often not appropriate for large problems and that heuristics and metaheuristics are therefore alternative solution approaches. The distinction between heuristics that build progressively the complete layout (i.e. construction heuristics) and heuristics that start from an initial solution and improve it through interchanging departments (i.e. improvement heuristics) is presented. CRAFT, a heuristic that uses pair-wise interchange of adjacent or equal area departments and considers minimization of distances (flow-distance or flow-unit cost-distance) as objective function criteria, is listed as an improvement heuristic as well as FRAT and DISCON.

(Meller & Kai-Yin, 1996) mention that FLP is concerned with finding the most efficient arrangement of *m* indivisible departments with unequal area requirements within a facility. (Meller & Kai-Yin, 1996) also mention that the better the arrangement, the faster the material handling because of the shorter distance traveled by significant flows between departments. Authors also clarify that the output of solving an FLP is a *block layout* which specifies the relative location of each department and that an additional step may be performed to obtain the *detailed layout*, which specifies input and output (I/O) locations, the layout inside each department and any aisle structures.

In (Rardin, 1998) it is mentioned that (1) FLP’s having more than 16 locations are amenable for solving heuristically, (2) determining the physical organization of a production system and the efficient design of its facilities is an important and fundamental strategic issue in manufacturing and (3) that the problem of locating input and output (I/O) points of each department and simultaneously finding the optimal *block layout* that minimizes the total traveled distance is still unsolved. Besides, in (Singh & Sharma, 2006) CRAFT is shown to be the most popular improvement heuristic. A list of other 34 heuristics to tackle the FLP is included. The list identifies if the heuristic solves the FLP using an adjacency or a distance (flow-distance or flow-unit cost-distance) objective function.

3. MCNEIL WAREHOUSE OPERATIONS

Raw donations and material classified as salvage/recycling are received at different Goodwill Industries of Central Texas stores. Some of these goods are sold in stores. Others must be sent to the McNeil or Springdale warehouses or to outside vendors because they are not successfully sold in the stores, they are not to be sold in stores, like metal to recycle and broken electronics or they are only needed in stores at particular times of the year, like the Halloween costumes. Because stores have only one loading/unloading dock it is convenient for them to sent all unwanted items to the McNeil warehouse regardless its final destination. The McNeil warehouse has a length of 192 feet, a width of 256 feet, and occupies a total area of 49,152 ft^2.

In the majority of the cases, stores send the goods to the McNeil warehouse packed in cardboard boxes (gaylords), plastic cars (duratainers), and plastic totes. Bulky items can come unpacked such as furniture. The specific final destination of the unit loads is properly labeled by the stores. Once unit loads arrive to the McNeil warehouse those that need to be shipped to Springdale or outside vendors (mostly gaylords and duratainers containing clothing, computers, books, shoes to send to Central American countries, cardboard and plastics) are moved using lift-trucks. Those unit loads to be sent to outside vendors are moved to a specific area in the warehouse where they wait to be loaded in trailers and dispatched to their final destinations as soon as possible. Unit loads that stores indicate are for the McNeil warehouse can contain TV's and similar electronics, pallets and empty unit loads, gaylords with Halloween costumes, material for auction, metal for recycling, and miscellaneous goods that deserve a last attempt to be sold in the Goodwill outlet store before being sent to trash or to auction. The Goodwill of Central Texas outlet store resides at the McNeil warehouse and it occupies 15,360 ft^2.

Those unit loads having outlet store as their destination are moved by lift-trucks to a tilting area where they are tilted into wood tables provided with wheels. Gaylords and duratainers are tilted by a machine operated by a warehouse employee while totes are manually emptied by another worker. Goods are accommodated on the tables to permit outlet customer's to look and buy the items easily. Once the tables are manually moved from the tilting area to the outlet store area they remain there for three or less days. Tables with any unsold items are moved to a sorting operation that classifies the product in different gaylords as suitable for auction, recycling, or trash. In some occasions items are broken into elements appropriate to send to Springdale warehouse, for example if they contain recyclable cardboard and plastic. All filled gaylords resulting from the sorting operation are moved to auction, recycling, trash, or Springdale/outside vendor areas using lift-trucks.

The McNeil warehouse has 6 loading doors located in the front area of the building to receive and dispatch trailers. The authors of this paper suggested management to dedicate and label these doors as follows. Doors 4-6, labeled as front door 1 in this study, are for receiving goods that stores indicated are for McNeil warehouse. Doors 1-3, labeled as front door 2 in this study, are for entering and removing goods that stores indicated are for Springdale warehouse or outside vendors. Specifically, authors suggested that doors 1-2 were dedicated to temporarily enter Springdale and outside vendors' loads into McNeil warehouse and door 3 was dedicated to moving those loads finally out of the McNeil warehouse.

The McNeil warehouse also hosts offices, a break-room, and a bathroom for warehouse employees. The four back doors of the warehouse can be dedicated also. Two of them can be used to move in and out items for auction (in this study those two doors are grouped and labeled as back door). Auctions take place roughly once per week outside the building close to the back area of the warehouse. Any items unsold in auction need to be moved again into the warehouse to the recycling, trash or to Springdale/outside vendors' area. Movement of material for auction is done using lift-trucks. One of the two other remaining back doors has the trash compactor near the trash area (in this study this door is grouped with the trash area). The remaining door is partially occupied by a roll-off bin used to accommodate the recycled metal coming from the metal balers (in this study this door is labeled as Roll-off).

After collecting information about unit loads content for near 250 trailers arriving to McNeil warehouse, flows (in trips per day) between all McNeil departments were estimated. Flows between department *i* and department *k* are notated as f_{ik}. The estimated flow data is summarized in Table 1 (from-to chart). A formulation of a FLP as a QAP problem follows (Equations 1-3). If a FLP is modeled as a QAP inter-departmental flows f_{ik} are an objective function parameter (input data). The other parameter (input data) in the model is d_{jl} and it represents the distance between layout locations *j* and *l*. The objective function is to minimize the total distance traveled (equation number 1). The binary decision variable x_{ij} takes the value of 1 if department i is assigned to location j, 0 otherwise. The binary decision variable x_{kl} takes the value of 1 if department k is assigned to location l and 0 otherwise. Assignment constraints guarantee that each department is assigned to one location (equation number 2) and that each location gets one department (equation number 3) (Rardin, 1998). Note that for the case when departments or facilities are not of the same area the formulation below can still be used if dividing the layout in blocks of equal size and assigning departments to occupy different number of blocks.

$$\min z = \sum_{i=1}^{n-1} \sum_{k>i}^{n} f_{ik} \sum_{j=1}^{n} \sum_{\substack{l=1 \\ l \neq j}}^{n} d_{jl} x_{ij} x_{kl} \tag{1}$$

$$\sum_{j=1}^{n} x_{ij} = 1 \qquad \forall i \tag{2}$$

$$\sum_{i=1}^{n} x_{ij} = 1 \qquad \forall j \tag{3}$$

Table 1: Flows (in Trips per Day) between McNeil Warehouse Operations

From To Chart																		
		Front Door 1	Front Door 2	Office	Break room	Tilting Area	Store	Sorting Area	Auction	Metal Recycling 1	Metal Recycling 2	Sorting TV's	Empties	Springdale	Roll-off	Trash	Back Door	Total
	Department	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1	Front door 1 (F1)	0	0	0	0	151	0	0	39	5.5	5.5	9	0	0	0	0	0	210.0
2	Front door 2 (F2)	0	0	0	0	0	0	0	0	0.0	0.0	0	0	70	0	0	0	70.0
3	Office (O)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
4	Breakroom (B)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
5	Tilting Area (T)	0	0	0	0	0	215	0	0	0	0	0	151	0	0	0	0	366.0
6	Store (S)	0	0	0	0	0	0	215	0	0	0	2	0	0	0	0	0	217.1
7	Sorting Area (S)	0	0	0	0	0	0	0	64	10.5	10.5	0	0	43	0	86	0	214.0
8	Auction (A)	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	108	110.0
9	Metal Recycling 1 (M)	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0.5
10	Metal Recycling 2 (M)	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0.5
11	Sorting TV's (S)	4	0	0	0	0	4	0	4	0	0	0	0	0	0	0	0	13.1
12	Empties (E)	188	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	188.0
13	Springdale (S)	0	113	0	0	0	0	0	0	0	0	0	0	0	0	0	0	113.0
14	Roll-off (R)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
15	Trash (T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
16	Back door B)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54	0	54.0
	Total	192	113	0	0	151	219	215	107	16	16	13	151	113	1	140	108	

4. PROBLEM DEFINITION AND METHODOLOGY

At the time management approached one of the authors of this paper, McNeil warehouse had a *block layout* that revealed some inefficiencies such as improper use of vertical spaces, cluttered aisles, not well-known department sizes, and location of some departments, such as the tilting operation, not following the process flow and generating excessive traveled distances. Furthermore, since several operations performed at both the McNeil and Springdale warehouses were to be consolidated into the McNeil warehouse, management needed to find a new layout showing exact department sizes, *detailed layouts* for the departments, and the optimal or near-optimal *block layout*. This non-trivial problem was decomposed into two phases being the first one to determine the required sizes and *detailed layouts* for each operation and the second one finding an optimal or near-optimal *block layout* for the whole warehouse.

4.1 Determining Sizes and Detailed Layouts for each Operation at McNeil Warehouse

To accomplish the first phase in this problem, queuing (waiting line) models were solved at the tilting, sorting, and metal recycling operations. The information about the type of unit-loads sent in 250 trailers and their destinations let to estimate the arrival rates and adjust probability distributions for the queuing models. Time studies and data provided by management let to estimate the service rates and their probability distributions. Table 2 summarizes the estimated arrival and service rates and some performance measures computed from queuing (waiting line) models. Those performance measures are the average number of unit loads at each operation, the average waiting time for a unit load and an estimation of the input buffer size and the associated probability that an arriving unit-load finds no space.

In the Goodwill problem, some operations had deterministic service times (D) and other ones resembled more to general (G) service time distributions than to exponential ones (M). The approach in this study was to solve both M/M/1 and M/D/1 (or M/G/1 if found more appropriate) models for single server queues. For multi-server queues the M/D/c model was computed since it was the model that resembled the best to the real case. Typically, queuing (waiting line) models assuming arrivals Poisson distributed and service times exponentially distributed are pessimistic if compared to the ones assuming other probability distributions for the service times. Performance measures in the first line at each entry row in Table 2 are from solving M/M models and numbers in the second line are from solving M/D or M/G models as it was applicable.

To determine the real sizes of each operation, besides input buffer sizes, it was necessary to account for space for machines and operators, output buffers, entrance and exit areas, and aisles. Several footprints for each operation were depicted in Microsoft Visio and discussed with management until arriving to consensus on a set of efficient *detailed layouts* for each operation.

Table 2: Estimated Sizes for Input Buffers from Running Waiting Line Models at Some McNeil Warehouse Operations

				Performance Measures				
Queue at Operation	Arrival rate (items/hour)	Service rate (items/hour&server)	Number of servers	Service time distribution	Average number in the system	Average waiting time in line (hrs)	Input buffer size	Probability of finding no space
Tilting: input buffer with duratainers and gaylords before mechanic tilting machine	11.34	13.51	1	M	5.383	0.400	16 duratainers and gaylords	5.5%
				G	3.120	0.200	9 duratainers and gaylords	4.5%
Tilting: input buffer with totes to be manually emptied into tables	60.91	120	1	M	1.027	0.009	14 totes (1 pallet)	0.0%
				D	0.767	0.004	5 totes (1 pallet)	0.1%
Sorting: input buffer with semi-full tables	21.49	8.30	3	M	N/A	N/A	N/A	N/A
				D	7.333	0.221	15 tables	11%
Metal recycling: input buffer with metal for recycling	3.25	10.00	1	M	0.482	0.0481	7 gaylords	0%
				D	0.403	0.0241	3 gaylords	0%

For computing the size of the Springdale/outside vendors' areas it was assumed that management will follow the authors' recommendation of installing a gravity flow rack. In the proposed layout for this area, this rack was oriented parallel to the wall containing the front loading docks. In this way the travel distance for loading and discharging the rack is the same. For computing the size of the warehouse area to store material marked for auction it was also assumed that a flow rack was to be installed. Using formulas in (Tompkins et al., 2010) for designing flow racks and considering unit load dimensions, desired clearances, rack characteristics, and an assumed storage height of 4 unit-loads, the optimal depth of a storage row or storage lane was computed for both Springdale/outside vendors and auction areas. Once it was corroborated that these optimal depths were implementable, the number of storage rows required to store the incoming product to those areas was computed. Since unit-loads to be sent to Springdale/outside vendors can be further classified according to its content, an optimal dedicated arrangement of these unit-loads in the flow rack was studied. The purpose was to determine which and how many storage rows to allocate to each inventory category. Unit-loads that are often received and therefore could leave more often such as clothes and computers were assigned to lanes near the front door while unit-loads received with less frequency like show boxes to donate to Central American countries were assigned to lanes farther from the front door.

4.2. Finding an Optimal or Near-optimal *Block Layout* for the Whole Warehouse.

The final outputs of phase one were (1) a *suggested initial block layout* showing accurate sizes for each operation and (2) efficient *detailed layouts* that considered lean manufacturing principles and that management was willing to implement at each operation. To keep the paper concise, the *detailed layouts* are not depicted in this paper. Figure 1 shows the *suggested initial block layout* (Navy Blue F = front doors (1&2), Green O = offices, Teal Blue B = Break-room, Maroon T = Tilting Area, Purple S = Store, Gray B = Back doors, Gold S = Sorting, Black A = Auction, Magenta S = Sprindgale, Red E = Empties, Sky Blue S = Sorting TV's, Green M = Metal Recycling 1, Blue M = Metal Recycling 2, Yellow T = Trash, Forest Green R = Roll-off bin)

r c	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8
1		O	O	B				S	S	S	S	S	S	S	S	S	S	B
2		O	O	T	T	T	T	S									S	B
3		O	O	T			T	S									S	B
4		O	O	T			T	S									S	B
5	F			T			T	S									S	B
6	F			T	T	T	T	S	S	S	S	S	S	S	S	S	S	B
7	F			S	S	S	S	S	S	S	S		A	A	A	A	A	
8	F			S	S	S	S	S	S	S	S		A				A	
9	F												A	A	A	A	A	
0	F	S	S	S	S	S	S	E	E									R
1	F	S					S	E	E	S	S	S	S				M	
2	F	S	S	S	S	S	S	E	E	S	S	S	S	M	M	T	T	T

Figure 1: Suggested *Initial Block Layout*

In phase two, it was necessary to find an optimal or near-optimal *block layout*. It was also of interest to identify how close the optimal or near-optimal *block layout* was from the *suggested* *initial block layout.* Since solving exactly a QAP formulation with such number of departments could be unsuccessful, the authors preferred to opt first for solving the problem heuristically. To accomplish this purpose, the whole warehouse area in the *suggested initial block layout* was partitioned in blocks of size 16’x16’ or 256 ft^2 and the coordinates of each department estimated accordingly. These discrete coordinates were inputted into the WinQSB Facility Location and Layout (FLL) module. The FLL module uses the Computerized Relative Allocation of Facilities Technique (CRAFT) algorithm (Chang, 2003). CRAFT computed centroid to centroid distances between departments under a rectilinear travel distance assumption. Using this information and also the flow matrix in Table 1, the CRAFT algorithm was run two times to produce new and improved layouts. The layouts satisfied a few imposed constraints related to keeping some departments or locations fixed.

However, the layout solutions provided by WinQSB after running CRAFT algorithm had some non-rectangular departments that could be odd to implement. Consequently, CRAFT solutions were massaged to arrive to a more realistic final layout. Figure 2 shows the CRAFT layout solution (top of the figure) and the final layout after massaging (bottom of the figure) for the scenario in which the only warehouse areas that remain fixed are the doors. Figure 3 shows the corresponding layouts for the scenario in which doors and the outlet store remain fixed.

Comparing the top and bottom layouts in Figure 2, in the final (or massaged) layout the store (purple S) area was moved up more to have a more rectangular shape. This caused the sorting area (gold S) to shift its area to the right making it also more rectangular. Because there is flow between metal recycling two (blue M2) and the sorting area the metal recycling two was moved closer up. Also, since the proposed plan for Springdale (pink S) area is to allocate the unit-loads in a gravity flow rack, it is not realistic to place the empties (red E) in front of the rack storage rows as shown in the layout at the top of Figure 2. Therefore, in the layout at the bottom of Figure 2 the area to allocate empties (E) was moved up next to the tilting area (maroon T) and arranged again to have a rectangular area. The layout at the bottom of Figure 3 is also the result of rearranging some departments for the sake of more realistic rectangular areas. Besides, in the layout at the bottom of Figure 3 only space for just one metal recycling station was allocated.

Originally, when entering the data into WinQSB, the front door areas (F1 and F2) and the areas outside of the warehouse (trash (T), back doors (B) and roll-off (R) were not included since they were technically outside the facility. This oversight produced misleading layouts. Since there are important flows through these doors and areas authors enlarged the layout to include these areas into WinQSB. As evidenced by the results in Figures 2 and 3, correcting this omission produced accurate layouts amenable to implement at the McNeil warehouse.

CRAFT Solution

	S	S	S				S	S	S	S	S	S	S	S	S	S	B
	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	B
	S	S	S							S	S	S	S	S	S	S	B
	S	S	S													S	B
F			S									S	S	S	S	S	B
F			S	S	S	S	S	S	S	S	S	M	T	T	T	T	B
F			T	T	T	T	T	T	T	T		A	A	A	A	A	
F			T	T	T	T	T	T	T	T		A				A	
F												A	A	A	A	A	
F	E	E	E	E	E	E	S	S									R
F	S	S	S	S	S	S		S	O	O	O	O				T	
F	S	S	S	S	S	S	S	S	O	O	O	O	M	M	B	T	T

Massaged Layout

	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	
	S	S	S							S	S	S	S	S	S	S	B
	S	S	S							S	S	S	S	S	S	S	B
	S	S	S	S								S	S	S	M2		B
F1			T	T	S	S	S	S	S	S	S				S		B
F1			T	T	T	T	T	T	T	T	S	S	S	S	S		B
F1			T	T	T	T	T	T	T	T		A	A	A	A	A	
F1			T	T	E	E	E	E	E	E		A				A	
F1												A	A	A	A	A	
F2	S	S	S	S	S	S											R
F2	S	S	S	S	S	S		O	O	O	O					T	
F2	S	S	S	S	S	S		O	O	O	O	B	M	M		T	T

Figure 2: Layouts for Scenario Fixed Doors Only

CRAFT Solution

	S	S	T				S	S	S	S	S	S	S	S	S	S	B
	S	S	T	T	T	T	S									S	B
	S	S	T			T	S									S	B
	S	S	T			T	S									S	B
F			T			T	S									S	B
F			T	T	T	M	S	S	S	S	S	S	S	S	S	S	B
F			S	S	S	S	S	S	S	S		A	A	A	A	A	
F			S	S	S	S	S	S	S	S		A				A	
F												A	A	A	A	A	
F	E	E	E	E	E	E	S	S									R
F	S	S	S	S	S	S		S	O	O	O	O				T	
F	S	S	S	S	S	S	S	S	O	O	O	O	M	M	B	T	T

Massaged Layout

	S	S	T	T	T	T	S	S	S	S	S	S	S	S	S	S	
	S	S	T			T	S									S	B
	S	S	T			T	S									S	B
	S	S	T			T	S									S	B
F1			T	T	T	T	S									S	B
F1	E2		E1	E1	E1	M2	S	S	S	S	S	S	S	S	S	S	B
F1	E2		S	S	S	S	S	S	S	S		A	A	A	A	A	
F1	E2		S	S	S	S	S	S	S	S		A				A	
F1												A	A	A	A	A	
F2	S	S	S	S	S	S											R
F2	S	S	S	S	S	S			O	O	O	O				T	
F2	S	S	S	S	S	S			O	O	O	O	B			T	T

Figure 3: Layouts for Scenario Fixed Doors and Store

5. NUMERICAL RESULTS

Figure 4 provides the areas for each department in number of blocks and in square feet for the *suggested initial block layout* and for the final (massaged) *block layouts* for each of the two scenarios studied (fixed doors only and fixed doors and store). We recall that the selected block size was 256 ft^2 (16'x16'). The penultimate row in the figure (green line) provides the total flow distance traveled in feet per day in each layout. It assumes centroid to centroid computation of distances and inter-departmental flows per day as given in Table 1. The numbers in this row also represent the optimal or near-optimal objective function value for a solution to the QAP presented in equations 1-3 and whose objective is to minimize total flow-distance traveled.

The total flow-distance values for *block layouts* in Scenario 1 and 2 are very close but they are about 37,211 feet per day smaller than the ones for the *initial block layout.* The main difference between both *block layouts* for scenarios 1 and 2 and the *initial block layout* is the location of the offices (green O), the break-room (teal blue B), and the sorting TV's area (light-blue S). In the *initial block layout* authors kept the offices (O), the outlet store (Purple S) and the front and back doors (F1, F2, B, R, T) in the actual positions they were in the Mc Neil warehouse when this study started. It was only after running CRAFT that it was detected that interchanging the location of the offices (O) and the break-room (B) with the location of the sorting TV areas (S) could reduce the total flow-distance significantly.

The real distance traveled between departments at the McNeil warehouse is not exactly the rectilinear centroid to centroid distance used by WinQSB Facility Location and Layout (FLL) module. In the McNeil warehouse setting, interdepartmental distances depend on the location of the input/output doors at each department, aisles, and paths used by the material handling systems. Considering this fact, the authors manually calculated the realistic distances traveled between departments in the massaged *block layouts* for each scenario and in the *suggested initial block layout*. Then, authors recomputed the objective function values or total flow-distances (in feet per day) for all cases. Thus, the last row in figure 4 (yellow line) provides the total flow distance traveled in feet per day in each layout considering real traveled distances and the inter-departmental flows per day as given in Table 1.

Figure 5 provides details for the resulting real flow-distances (traveled feet per day) between all warehouse locations for the *initial block layout* and each scenario studied. Last number in each of the three tables in Figure 5 presents the total flow times distance (flow-distance) for the each layout. The flow-distance traveled in the *initial block layout* is 192,102 feet per day. The flow-distance traveled in the massaged layout assuming just fixed doors goes down to 102,156 (a saving of 89,946 feet per day vs. *the initial block layout*). The flow-distance traveled for the massaged layout assuming both fixed doors and store goes a little more down to 90,653 (a saving of 101,449 feet per day vs. *the initial block layout*). Thus, these objective function values direct the optimal choice for Goodwill managers to the second scenario, the massaged layout with fixed doors and store.

Comparison of Original Layout and WinQSB Results for the Two Scenarios Studied									
		Original Coordinates		Original Layout with Fixed Doors		Scenario 1. Massaged Layout after Running WinQSB with Fixed Doors		Scenario 2. Massaged Layout after Running WinQSB with Fixed Doors and Store	
Area #	Room	Top Left	Bottom Right	Area (Blocks)	Area (Sq. Ft)	Area (Blocks)	Area (Sq. Ft)	Area (Blocks)	Area (Sq. Ft)
1	Front Door 1	(5,1)	(9,1)	5	0	5	0	5	0
2	Front Door 2	(10,1)	(12,1)	3	0	3	0	3	0
3	Office	(1,2)	(4,3)	8	2048	8	2048	8	2048
4	Breakroom	(1,4)	(1,4)	1	256	1	256	1	256
5	Tilting Area	(2,4)	(6,7)	20	5120	20	5120	20	5120
6	Store	(1,8)	(6,17)	60	15360	54	13824	60	15360
7	Sorting Area	(7,4)	(8,11)	16	4096	16	4096	16	4096
8	Auction	(7,13)	(9,17)	15	3840	15	3840	15	3840
9	Metal Recycling 1	(12,14)	(12,15)	2	512	2	512	0	0
10	Metal Recycling 2	(11,17)	(11,17)	1	256	1	256	1	256
11	Sorting TVs	(11,10)	(12,13)	8	2048	8	2048	8	2048
12	Empties	(10,8)	(12,9)	6	1536	6	1536	3	768
13	Springdale	(10,2)	(12,7)	18	4608	18	4608	18	4608
14	Trash	(12,16)	(12,18)	3	768	3	768	3	768
15	Backdoor	(1,18)	(6,18)	6	0	5	0	5	0
16	Roll-Off	(10,18)	(10,18)	1	256	1	256	1	256
17	Empties 2 (Only for scenario 2 fixed doors and store)							3	768
Total area				173	40704	166	39168	170	40192
Total area originally available including aisles (sqt. ft)	49152			Total flow*Distance (trips per day) (Using distance centroid to centroid)	215,080		177,291		177,867.14
				Total flow*Distance (trips per day) (Using real distances traveled between locations)	192,102.00		102,156.00		90,652.83

Figure 4: Numerical Results Comparison Initial Block Layout vs. Massaged Layouts for the Two Scenarios Studied

6. CONCLUSIONS AND FURTHER RESEARCH

Managers at Goodwill Industries of Central Texas aimed to consolidate some warehouse operations performed at two different warehouses, McNeil and Springdale into a single warehouse (Mc Neil). Industrial Engineering techniques related to queuing theory (waiting line models), facility layout, material handling, and lean manufacturing demonstrated to be valuable to management. Authors used a two-phase decomposition approach to solve the problem. First, queuing (waiting line) models, time studies, material handling knowledge, and the Visio drawing package permitted to compute realistic areas (in square feet) and produce *detailed layouts* for each department or operation to be hosted in the McNeil warehouse. Applying these techniques it was also possible to propose an *initial block layout*. Second, the CRAFT heuristic permitted to generate a couple of more optimal *block layouts* for the 16 departments McNeil warehouse. Both CRAFT layouts (after some massaging step performed by the authors) were an improvement in the total flow-distance traveled if compared to the *initial block layout*. The fist scenario generated with CRAFT is when all departments inside the warehouse can be relocated. The second one is when the outlet store is kept fixed. Since there was a cost in relocating the offices and the outlet store, it was amenable to learn that the second scenario, which only requires relocating the offices, was the best among all layouts compared. It is proposed as further research to investigate the possibility to solve exactly a quadratic programming model for this problem. The idea is to compare the two heuristic solutions presented in this paper to the really optimal one.

FLOWS_TIMES_DISTANCES FOR INITIAL LAYOUT

Area #	From\To	Front Door 1	Front Door 2	Office	Break room	Tilting Area	Store	Sorting Area	Auction	Metal Recycling 1	Metal Recycling 2	Sorting TVs	Empties	Springdale	Roll-off	Trash	Backdoor	Total
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1	Front Door 1	0	0	0	0	9135.50	0	0	9106.50	1575.29	1737.54	2151.00	0	0	0	0	0	23705.83
2	Front Door 2	0	0	0	0	0	0	0	0	0	0	0	0	6090.00	0	0	0	6090.00
3	Office	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
4	Breakroom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
5	Tilting Area	0	0	0	0	0	6629.17	0	0	0	0	0	40266.67	0	0	0	0	46895.83
6	Store	0	0	0	0	0	0	5498.83	0	0	0	142.33	0	0	0	0	0	5641.17
7	Sorting	0	0	0	0	0	0	0	12656.00	2569.00	2878.75	0	0	12004.17	0	24610.33	0	54718.25
8	Auction	0	0	0	0	0	0	0	0	0	0	91.32	0	0	0	0	8909.87	9001.19
9	Metal Recycling 1	0	0	0	0	0	0	0	0	0	0	0	0	0	38.04	0	0	38.04
10	Metal Recycling 2	0	0	0	0	0	0	0	0	0	0	0	0	0	6.42	0	0	6.42
11	Sorting TVs	879.78	0	0	0	0	400.49	0	348.93	0	0	0	0	0	0	0	0	1629.21
12	Empties	31611.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31611.33
13	Springdale	0	7486.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7486.25
14	Roll-off	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
15	Trash	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
16	Backdoor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5278.5	0	5278.50
	Total	32491.11	7486.25	0.00	0.00	9135.50	7029.66	5498.83	22111.43	4144.29	4616.29	2384.65	40266.67	18094.17	44.46	29888.83	8909.87	192102.02

FLOWS_TIMES_DISTANCES FOR MASSAGED LAYOUT WITH FIXED DOORS

Area #	From\To	Front Door 1	Front Door 2	Office	Break room	Tilting Area	Store	Sorting Area	Auction	Metal Recycling 1	Metal Recycling 2	Sorting TVs	Empties	Springdale	Roll-off	Trash	Backdoor	Total
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1	Front Door 1	0	0	0	0	4832.00	0	0	9204.00	1980.00	2090.00	324.00	0	0	0	0	0	18430.00
2	Front Door 2	0	0	0	0	0	0	0	0	0	0	0	0	332.50	0	0	0	332.50
3	Office	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
4	Breakroom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
5	Tilting Area	0	0	0	0	0	4676.25	0	0	0	0	0	604	0	0	0	0	5280.25
6	Store	0	0	0	0	0	0	859.75	0	0	0	8.71	0	0	0	0	0	868.47
7	Sorting	0	0	0	0	0	0	0	3072.00	0.00	84.00	0	0	12857	0	9632.00	0	25645.00
8	Auction	0	0	0	0	0	0	0	0	0	0	928.62	0	0	0	0	1347.26	2275.88
9	Metal Recycling 1	0	0	0	0	0	0	0	0	0	0	0	0	0	33.00	0	0	33.00
10	Metal Recycling 2	0	0	0	0	0	0	0	0	0	0	0	0	0	57.25	0	0	57.25
11	Sorting TVs	209.14	0	0	0	0	17.43	0	958.57	0	0	0	0	0	0	0	0	1185.14
12	Empties	42952.56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42952.56
13	Springdale	0	452.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	452.00
14	Roll-off	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
15	Trash	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
16	Backdoor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4644.00	0	4644.00
	Total	43161.70	452.00	0.00	0.00	4832.00	4693.68	859.75	13234.57	1980.00	2174.00	1261.33	604.00	13189.50	90.25	14276.00	1347.26	102156.04

FLOWS_TIMES_DISTANCES FOR MASSAGED LAYOUT WITH FIXED DOORS AND STORE

Area #	From\To	Front Door 1	Front Door 2	Office	Break room	Tilting Area	Store	Sorting Area	Auction	Empties 2	Metal Recycling 2	Sorting TVs	Empties	Springdale	Roll-off	Trash	Backdoor	Total
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1	Front Door 1	0	0	0	0	4832.00	0	0	9243.00	0	990.00	234.00	0	0	0	0	0	15299.00
2	Front Door 2	0	0	0	0	0	0	0	0	0	0	0	0	350.00	0	0	0	350.00
3	Office	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
4	Breakroom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
5	Tilting Area	0	0	0	0	0	1414.70	0	0	0	0	0	453.00	0	0	0	0	1867.70
6	Store	0	0	0	0	0	0	3331.54	0	0	0	192.63	0	0	0	0	0	3524.17
7	Sorting	0	0	0	0	0	0	0	1024.00	0	87.36	0	0	2881.00	0	24768.00	0	28760.36
8	Auction	0	0	0	0	0	0	0	0	0	0	674.27	0	0	0	0	7777.46	8451.72
9	Empties 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
10	Metal Recycling 2	0	0	0	0	0	0	0	0	0	0	0	0	0	352.17	0	0	352.17
11	Sorting TVs	444.43	0	0	0	0	638.67	0	954.21	0	0	0	0	0	0	0	0	2037.31
12	Empties	14662.14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14662.14
13	Springdale	0	10650.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10650.25
14	Roll-off	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
15	Trash	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
16	Backdoor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4698.00	0	4698.00
	Total	15106.57	10650.25	0.00	0.00	4832.00	2053.37	3331.54	11221.21	0.00	1077.36	1100.90	453.00	3231.00	352.17	29466.00	7777.46	90652.826

Figure 5: Flow-Distance Values for all Layouts Analyzed

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